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THE EFFECT OF FUEL COMPOSITION ON GROUNDFALL FROM AIRCRAFT FUEL--ETC(U)
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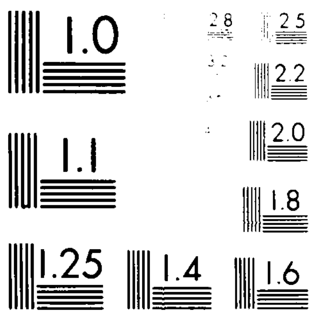
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THE EFFECT OF FUEL COMPOSITION ON GROUNDFALL FROM AIRCRAFT FUEL JETTISONING

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HARVEY J. CLEWELL III
ENVIRONICS DIVISION
ENVIRONMENTAL SCIENCES BRANCH

MARCH 1981

FINAL REPORT
MARCH 1980 — FEBRUARY 1981

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A computer model which simulates the evaporation and free-fall of fuel droplets in the atmosphere was used to determine the effect of fuel composition on the nature and extent of ground contamination by fuel discharged from an aircraft in flight. Three fuel compositions were used: (1) JP-4, the standard Air Force jet fuel; (2) Jet A (JP-8), the standard U.S. commercial jet fuel; and (3) Number 2 Diesel Fuel, representing the upper limit for future, broadened-specification fuels from alternative sources. The results of this study indicate that the

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amount of liquid fuel reaching the ground from the jettisoning of commercial jet fuels is much greater than for JP-4. Moreover, future broadened specification fuels may produce even greater ground contamination when jettisoned. As an example, for JP-4 jettisoned 1500 meters above the ground at 0°C, less than two percent of the fuel would reach the ground before evaporating. Under these same conditions, the fraction of Jet A and Number 2 Diesel Fuel reaching the ground would be 30 and 70 percent, respectively.

The report includes graphs and tables for use in estimating the likelihood of significant ground-contamination following a specific fuel jettisoning incident.

PREFACE

This report was prepared by the HQ AFESC Engineering and Services Laboratory, Tyndall Air Force Base, Florida. It documents work performed between March 1980 and February 1981 under Program Element 62601F, Project 19004C02. The author and project officer was Captain Harvey J. Clewell.

This report describes a study performed to determine the effect of fuel composition on the nature and extent of ground contamination by fuel jettisoned from aircraft in flight. The environmental implications of jettisoning JP-4 jet fuel have been described in previous reports. This report provides information on the differential impact of jettisoning commercial jet fuel (Jet A or JP-8) or future broadened-specification fuels (represented by Number 2 Diesel Fuel). The information in this report can be used to support environmental impact assessments and to estimate the local impact of specific fuel-jettisoning incidents.

This report has been reviewed by the Public Affairs Office and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

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SECTION I
INTRODUCTION

The term "fuel jettisoning" refers to the discharge of unburned fuel directly into the atmosphere by an airborne aircraft. Fuel jettisoning usually occurs as the result of an in-flight emergency or unforeseen operational requirement and is performed to reduce the aircraft's gross weight and facilitate a safe, expeditious landing. The jettisoned fuel readily breaks up into small droplets and begins to evaporate. From an environmental standpoint, the principal concern is what fraction of the fuel reaches the ground before it can evaporate and disperse. Reference 1 shows that the effect of the evaporated fuel vapors in the atmosphere is negligible. If liquid fuel reaches the ground, however, there is a potential for negative environmental consequences such as crop damage or water pollution.

The fraction of jettisoned fuel reaching the ground in a given circumstance depends upon the fuel's volatility, or tendency to evaporate. The fuel's volatility, in turn, depends on its composition. The purpose of this study was to determine the effect of fuel composition on the nature and extent of ground contamination by liquid fuel. Three fuel compositions were chosen: (1) JP-4, the standard Air Force jet fuel; (2) Jet A (JP-8), the standard US commercial jet fuel; and (3) Number 2 Diesel Fuel, representing the upper limit for future broadened-specification fuels from alternative sources. The fraction of these fuels reaching the ground under various conditions was modeled. This information can be used to estimate the local impact of fuel jettisoning incidents. It will also be of use in determining the environmental impact of converting aircraft from JP-4 to JP-8, as well as for future conversion to alternative fuels.

SECTION II
BACKGROUND

The combined pressures of rising jet fuel prices, diminishing oil reserves, and increasing dependence on foreign crude oil suppliers have spurred investigation of the possibility of relaxing the specifications for current jet aircraft fuels. Broadened fuel specifications would allow a greater yield of jet fuels from present crude stocks, particularly from lower quality crudes, increasing availability and lowering costs. Also, relaxed fuel specifications would reduce the degree of refining required for fuels derived from alternative sources such as oil shale, tar sands, or coal. In fact, the use of such alternative fuels may prove to be economically infeasible without some changes to specifications. Unfortunately, the acceptance of broadened-specification fuels entails several trade-offs in the areas of engine performance and environmental impact. These trade-offs must be considered as new specifications are being set.

Changing fuel composition can be anticipated to have an important environmental consequence in the area of fuel jettisoning. The Air Force has been investigating the environmental ramifications of this practice for several years, and the results of this investigation have been published in References 1, 2, and 3. Air Force aircraft jettison fuel nearly a thousand times a year. The fuel released to the atmosphere by these aircraft amounts to more than seven thousand metric tons (sixteen million pounds) per year -- averaging twenty-six thousand liters (seven thousand gallons) per day (Reference 1). Fortunately, the fuel discharged by Air Force aircraft is generally JP-4, a highly volatile fuel which is readily evaporated and dispersed, minimizing ground contamination by liquid fuel. However, as relaxed fuel specifications extend the boiling range and decrease the volatility of future fuels, ground contamination will become more of a problem.

Jet A, the fuel currently in use by commercial aircraft in the US, is a kerosene type fuel much less volatile than JP-4. Recently the Air Force converted all of its NATO aircraft to JP-8, the military equivalent of Jet A. Any fuel jettisoning involving these fuels can be expected to entail greater ground contamination than that involving JP-4. In recent years, Air Force aircraft in NATO have jettisoned fuel approximately 80 times per year, for a total of over five hundred metric tons (over a million pounds) of fuel per year (Reference 1). Commercial aircraft also jettison fuel, but complete records are not kept. Maintenance reports provided to the FAA by the commercial airlines show 485 records of fuel jettisoned over the 5-year period ending March, 1980. Unfortunately, these records do not indicate the amount of fuel jettisoned, and only fuel jettisoning incidents associated with aircraft maintenance are included. Nevertheless, we can conclude that the level of fuel jettisoning by commercial aircraft is significant, particularly considering the increased likelihood of ground contamination from commercial jet fuel as compared to JP-4.

In order to assess the differential impact of fuel jettisoning involving broadened-specification fuels and Jet A/JP-8 , a computer model was employed which simulates the evaporation and free-fall of fuel droplets in the atmosphere. This model, described in detail in Reference 3, breaks up a droplet's fall into a series of small time intervals. During each interval the distance of fall and loss of mass are calculated, providing the initial conditions for the next interval. This stepwise approximation continues until the droplet impacts on the ground or evaporates completely. To simulate fuel jettisoning, the model is run for a series of droplets based on actual experimental measurements of the fuel droplet size distribution produced by aircraft fuel jettisoning (see Reference 3). A detailed composition of the jettisoned fuel must be input into the model for use in the evaporation calculations. The model then keeps track of the changing composition as the more volatile components evaporate preferentially, leaving the denser, slower-evaporating components behind. In previous reports (References 1, 2, and 3) only a composition for JP-4 was used. In this report the effect of changing the initial fuel composition is explored.

SECTION III
FUEL COMPOSITIONS

The composition of JP-4 shown in Table 1a was based on an analysis provided by the Air Force Aero-Propulsion Laboratory. This is the same composition used in previous reports concerning fuel jettisoning (References 1, 2, and 3). The vapor pressure of this representative mixture at 38°C (100°F) is 3.0 pounds per square inch, which is within the range of Reid vapor pressures typically measured for JP-4 (Reference 4). Similarly, the overall density, average carbon number, and total aromatic content shown in the Table 1a are typical values for JP-4.

The composition of the Jet A/JP-8 shown in Table 1b was based on analyses of Jet A from Reference 5. Comparison with analyses of JP-8 from Reference 6 confirms that this composition can be used to represent both Jet A and JP-8. Although the Navy's JP-5 jet fuel has a somewhat higher initial boiling point than these two fuels, the overall boiling range is very similar. Therefore, the fuel jettisoning predictions in this report using the Jet A composition should apply to incidents involving JP-5 as well.

The exact nature of future broadened-specification fuels is not known, and predictions of likely properties vary. The primary fuel used by NASA to represent future fuels is known as the Experimental Referee Broadened-Specification (ERBS) fuel, and is very similar to Number 2 Diesel Fuel (DF #2). Recent Air Force studies of the effect of future fuel properties on gas turbine engine performance, emissions, and durability have used a matrix of fuels to span possible future variations (Reference 6). The most important fuel property affecting droplet evaporation is the boiling range. The boiling range of the fuels used in these studies to represent possible broadened-specification fuels varies from that of JP-4 at one extreme to that of DF #2 at the other. (The boiling ranges of JP-4, JP-8/Jet A, and DF #2 are compared in Figure 1.) Therefore, in keeping with these studies, DF #2 will be used to represent the upper limit of potential broadened-specification fuel compositions. The composition of DF #2 used in this study was based on Reference 5 and is shown in Table 1c. The boiling ranges shown in Figure 1 correspond to the fuel compositions shown in Table 1.

Table 1. FUEL COMPOSITIONS

a. JP-4

Components	Volume Percent	Molecular Weight	Boiling Point (°C)	Density (g/ml)
C5* hydrocarbons	3.9	72.2	28	.62
C6 paraffins	8.1	86.2	60	.66
C6 cycloparaffins	2.1	84.2	81	.78
Benzene	0.3	78.1	80	.88
C7 paraffins	9.4	100.2	92	.69
C7 cycloparaffins	7.1	98.2	101	.77
Toluene	0.7	92.1	111	.87
C8 paraffins	10.1	114.2	118	.70
C8 cycloparaffins	7.4	112.2	124	.78
C8 aromatics	1.6	106.2	139	.87
C9 paraffins	9.1	128.3	142	.72
C9 cycloparaffins	4.3	126.2	154	.80
C9 aromatics	2.4	120.2	165	.88
C10 paraffins	7.3	142.3	160	.72
C10 cycloparaffins	3.7	140.3	171	.80
C10 aromatics	1.8	134.3	177	.86
Napthalene	0.2	128.2	218	1.03
C11 paraffins	4.8	156.3	196	.74
C11 cycloparaffins	2.5	154.3	196	.80
Dicycloparaffins	3.4	150.3	201	.89
C11 aromatics	1.1	148.2	205	.86
C11 napthalenes	0.2	142.2	245	1.02
C12 paraffins	2.8	170.3	216	.75
C12 cycloparaffins	1.2	168.3	211	.80
C12 aromatics	0.5	162.3	216	.86
C12 napthalenes	0.2	156.2	268	1.00
C13 paraffins	1.1	184.4	235	.76
C13 cycloparaffins	0.4	182.4	225	.80
C13 aromatics	0.1	176.3	234	.87
C14 hydrocarbons	0.2	198.4	254	.76
C15 hydrocarbons	0.1	212.4	271	.77
Tricycloparaffins	1.8	192.4	290	.94
Residual hydrocarbons	0.1	202.3	393	1.27

Density of mixture: 0.75 g/ml
Average carbon number: C9
Total aromatics: 9.2%

*That is, components containing 5 carbon atoms

Table 1. FUEL COMPOSITIONS (CONTINUED)

b. JP-8/Jet A

Components	Volume Percent	Molecular Weight	Boiling Point (°C)	Density (g/ml)
C8 paraffins	0.3	114.2	118	0.70
C8 cycloparaffins	0.2	112.2	124	0.78
C8 aromatics	0.1	106.2	139	0.87
C9 paraffins	2.4	128.3	142	0.72
C9 cycloparaffins	1.5	126.2	154	0.80
C9 aromatics	1.0	120.2	165	0.88
C10 paraffins	5.6	142.3	160	0.72
C10 cycloparaffins	3.5	140.3	171	0.80
C10 aromatics	2.3	134.2	177	0.86
C11 paraffins	8.7	156.3	196	0.74
C11 cycloparaffins	3.3	154.3	196	0.80
Dicycloparaffins	3.1	152.3	201	0.89
C11 aromatics	3.6	148.2	205	0.86
C12 paraffins	10.8	170.3	216	0.75
C12 cycloparaffins	8.0	166.3	221	0.88
C12 aromatics	4.6	162.3	216	0.86
C13 paraffins	11.5	184.4	235	0.76
C13 cycloparaffins	8.5	182.4	225	0.80
C13 aromatics	4.9	176.3	234	0.87
C14 paraffins	5.9	198.4	254	0.76
C14 cycloparaffins	4.4	192.4	290	0.94
C14 aromatics	2.5	186.3	295	1.03
C15 paraffins	1.4	212.4	271	0.77
C15 cycloparaffins	1.0	206.4	300	0.90
C15 aromatics	0.6	200.4	305	0.95
C16 hydrocarbons	0.2	226.4	287	0.77
Residual hydrocarbons	0.1	202.3	393	1.27

Density of mixture: 0.81 g/ml
Average carbon number: C12
Total aromatics: 19.6%

Table 1. FUEL COMPOSITIONS (CONCLUDED)

c. DF #2

Components	Volume Percent	Molecular Weight	Boiling Point (°C)	Density (g/ml)
C10 paraffins	0.9	142.3	160	0.72
C10 cycloparaffins	0.6	140.3	171	0.80
C10 aromatics	0.4	134.2	177	0.86
C11 paraffins	2.3	156.3	196	0.74
C11 cycloparaffins	1.7	152.3	201	0.89
C11 aromatics	1.0	148.2	205	0.86
C12 paraffins	3.8	170.3	216	0.75
C12 cycloparaffins	2.8	166.3	221	0.88
C12 aromatics	1.6	162.3	216	0.86
C13 paraffins	6.4	184.4	235	0.76
C13 cycloparaffins	4.8	182.4	225	0.80
C13 aromatics	2.8	176.3	234	0.87
C14 paraffins	8.8	198.4	254	0.76
C14 cycloparaffins	6.6	192.4	290	0.94
C14 aromatics	3.8	186.3	295	1.03
C15 paraffins	7.4	212.4	271	0.77
C15 cycloparaffins	5.5	206.4	300	0.90
C15 aromatics	3.2	200.4	305	0.95
C16 paraffins	5.8	226.4	287	0.77
C16 cycloparaffins	4.4	222.4	295	0.88
C16 aromatics	2.5	214.4	325	0.95
C17 paraffins	5.5	240.5	303	0.78
C17 cycloparaffins	4.1	236.5	310	0.88
C17 aromatics	2.4	232.5	305	0.89
C18 paraffins	4.3	254.5	306	0.78
C18 cycloparaffins	3.2	248.5	335	0.90
C18 aromatics	1.8	242.5	340	1.00
C19 paraffins	0.7	268.5	330	0.78
C19 cycloparaffins	0.6	262.5	360	0.90
C19 aromatics	0.3	244.5	400	1.20

Density of mixture: 0.84 g/ml
Average carbon number: C15
Total aromatics: 19.7%

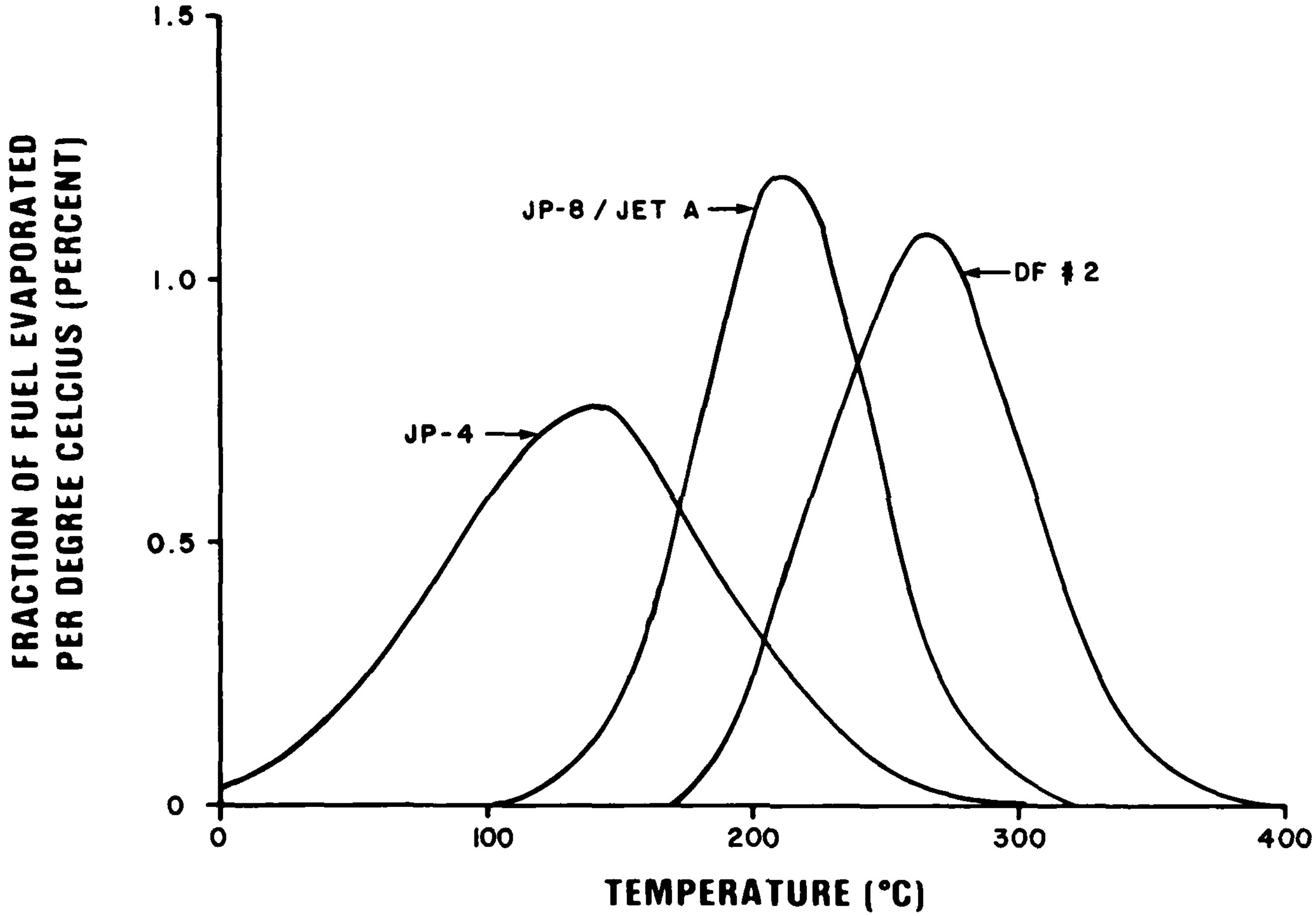

Figure 1. Comparison of Boiling Range of Different Fuels

SECTION IV
RESULTS

The predictions of the fuel droplet evaporation and free-fall model for JP-4, JP-8/Jet A, and DF #2 are shown in Figures 2, 3, and 4. Figure 2 shows the effect of the altitude (above local ground level) at which the fuel is jettisoned on the fraction of fuel reaching the ground. In all cases the effect diminishes as the altitude increases, and above 3000 meters (10,000 feet) there is essentially no change in the amount of liquid fuel reaching the ground for different release altitudes. Below 1500 meters (5000 feet) the fraction of fuel reaching the ground increases sharply because the fuel no longer has sufficient time to evaporate before it strikes the ground.

The effect of ambient temperature is shown in Figure 3. The temperature of interest is that measured at ground-level. The model uses a standard lapse rate to calculate the temperature at higher altitudes. The effect of temperature is very strong: a 20°C (36°F) change in temperature can produce as much as a factor of ten change in the amount of liquid fuel reaching the ground. Some corresponding predictions from Figure 3 for the three different fuels are compared in Figure 4. The jettisoning altitude in this case is 1500 meters. At the same temperature considerably more JP-8/Jet A reaches the ground than JP-4. The situation for DF #2 is even worse. Except for high ambient temperatures, most of the jettisoned DF #2 will reach the ground before evaporating. For example, at 0°C (32°F) less than 2 percent of the JP-4 jettisoned would reach the ground before evaporating; under the same conditions the fractions of JP-8/Jet A and DF #2 reaching the ground would be 30 and 70 percent, respectively.

Due to their higher terminal velocity, the largest fuel droplets produced in the jettisoning process are the first to reach the ground. The average fall rates predicted for the first droplets to reach the ground under various conditions are shown in Table 2. The most striking feature of these results is that except for JP-8/Jet A at 40°C, the average fall rate for the largest droplets is essentially independent of the release altitude. The average values shown in this table can be used to predict the effect of winnowing on the dispersion of the fuel droplets, as discussed in Reference 1.

The composition of the fuel droplets which reach the ground is no longer the same as that of the fuel which was jettisoned. The more volatile, lower molecular weight components evaporate off preferentially, and the droplets end up containing a residual mixture of the higher molecular weight components. Typical compositions for fuel droplets reaching the ground are shown in Table 3. When ambient temperatures are sufficiently low so that a significant fraction of jettisoned JP-4 will be unable to evaporate, the composition of the droplets reaching the ground

resembles JP-8/Jet A more than JP-4. This is because the more volatile components have been stripped away. Similarly, when JP-8 or Jet A is jettisoned, the liquid fuel reaching the ground resembles DF #2 more than JP-8/Jet A. This fact is important in considering the effect of the liquid fuel in water/soil environments.

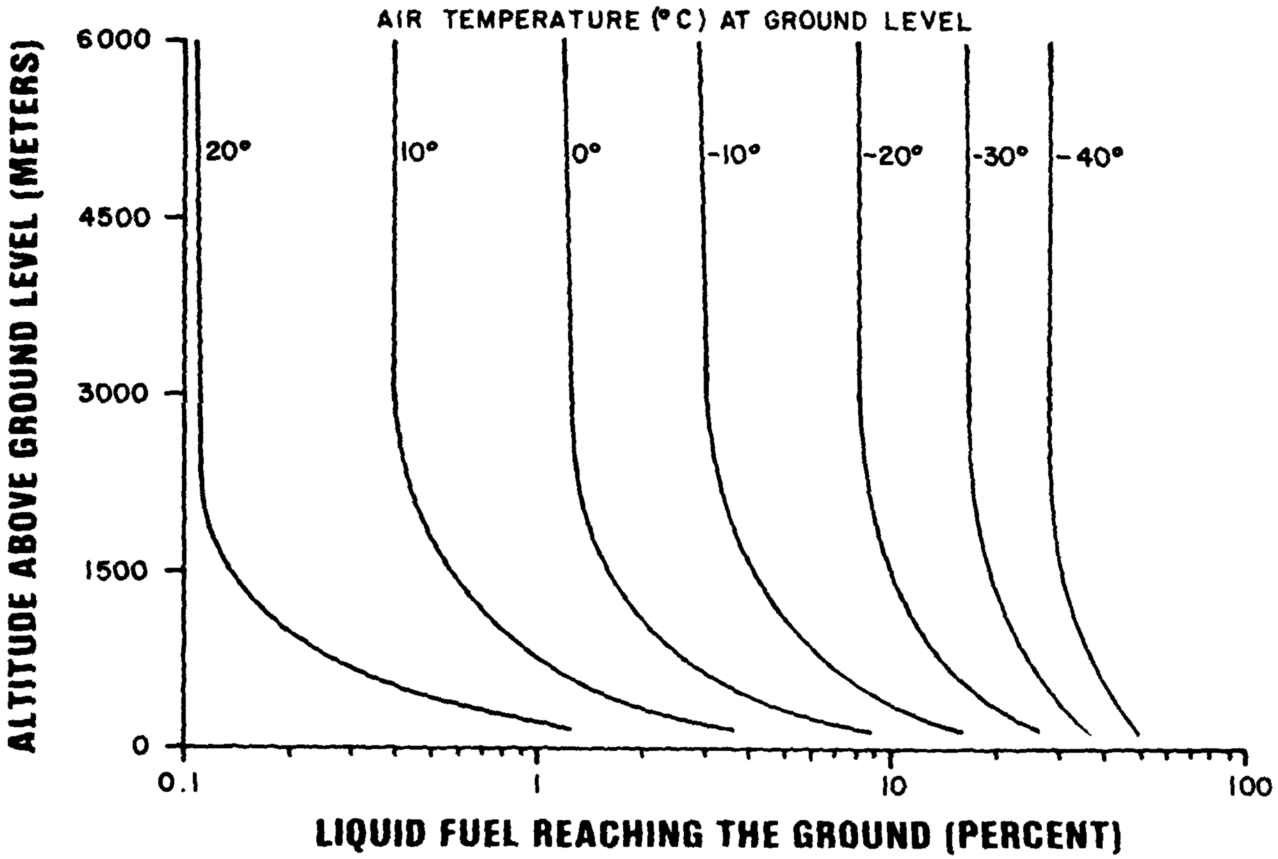

Figure 2a. Effect of Release Altitude on the Percent of Fuel Reaching the Ground: JP-4.

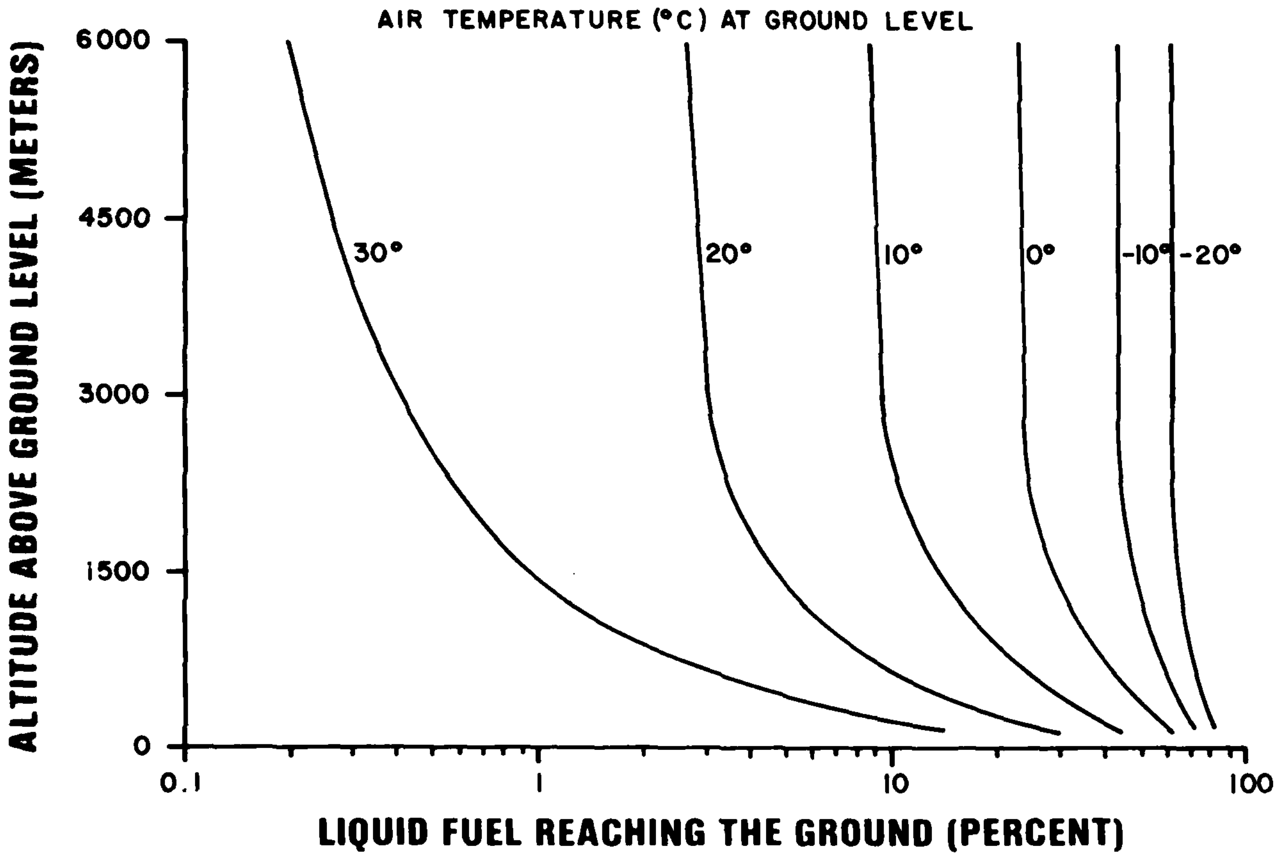

Figure 2b. Effect of Release Altitude on the Percent of Fuel Reaching the Ground: JP-8/Jet A.

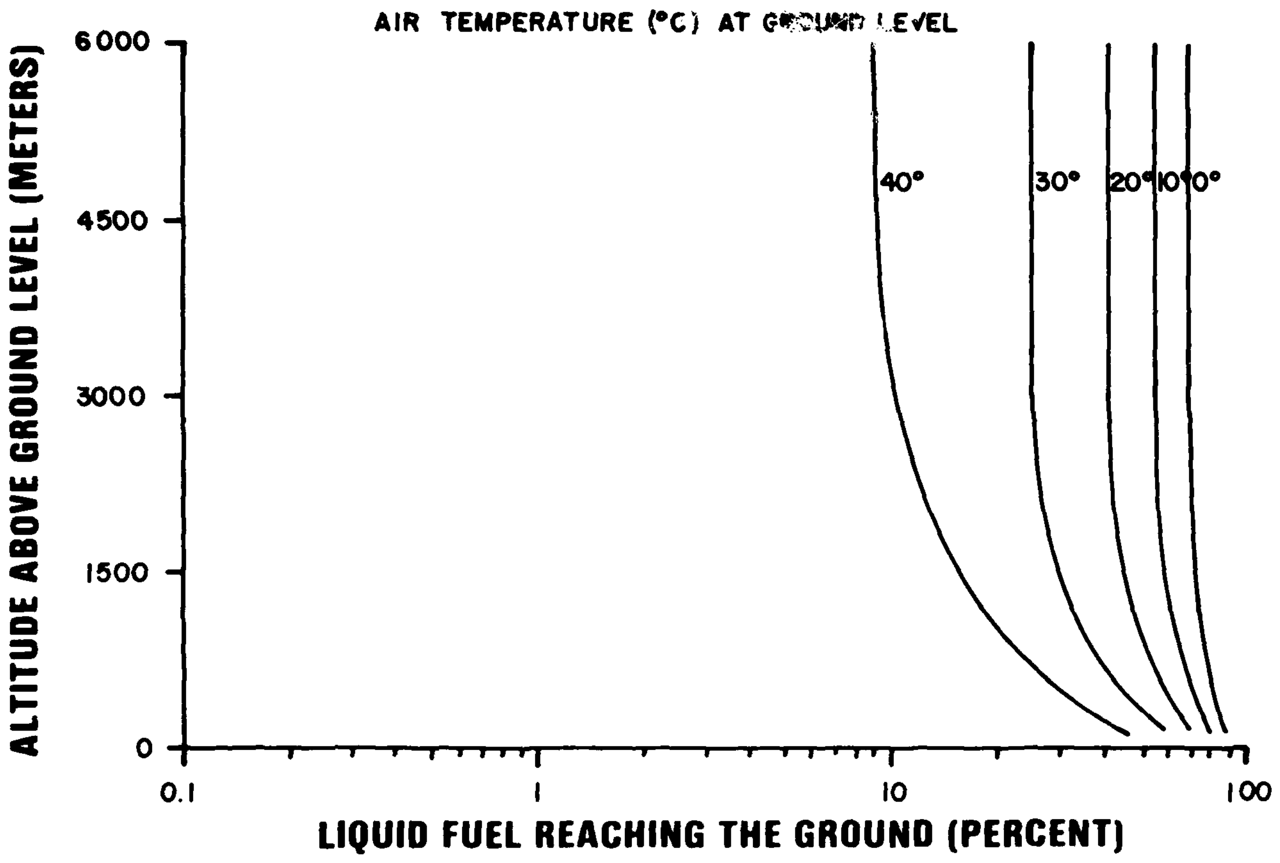

Figure 2c. Effect of Release Altitude on the Percent of Fuel Reaching the Ground: DF#2.

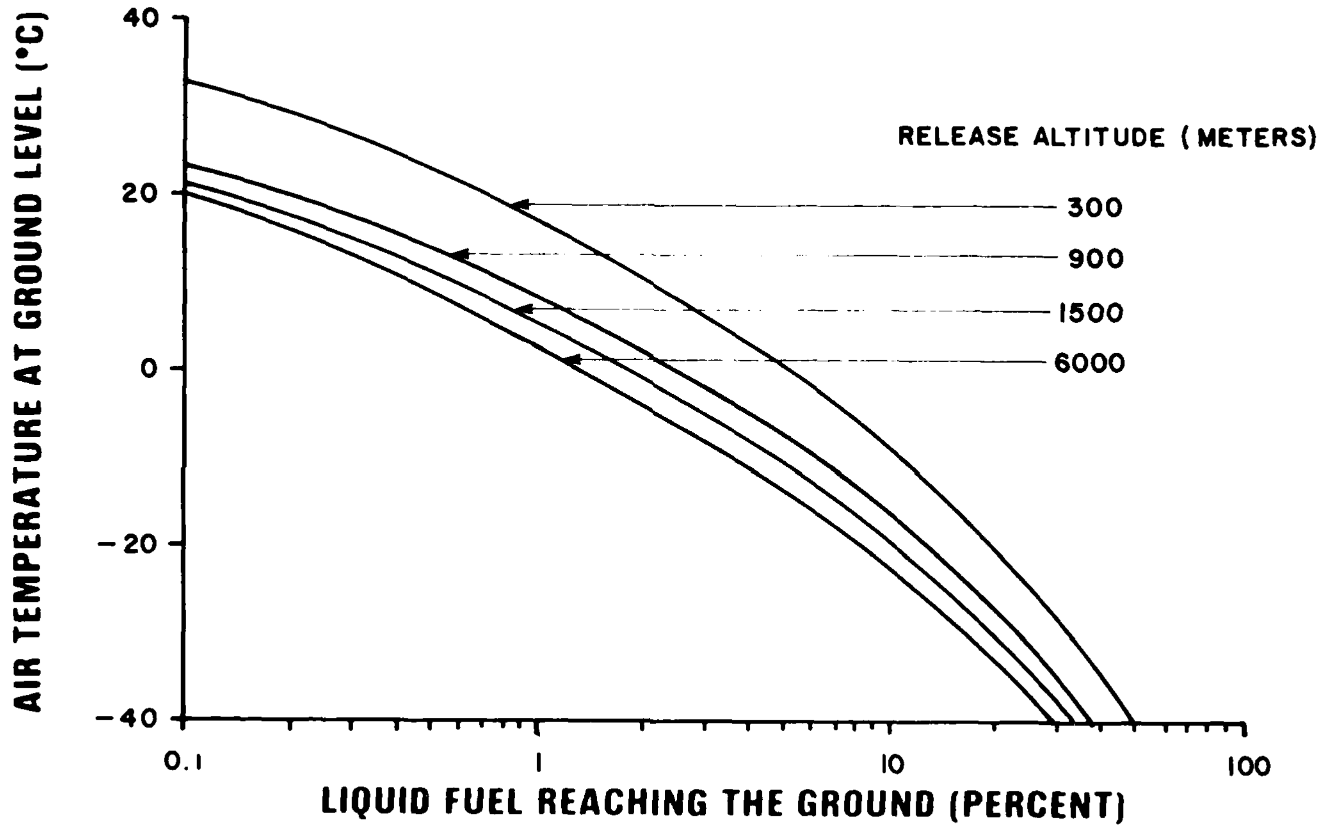

Figure 3a. Effect of Temperature on the Percent of Fuel Reaching the Ground: JP-4.

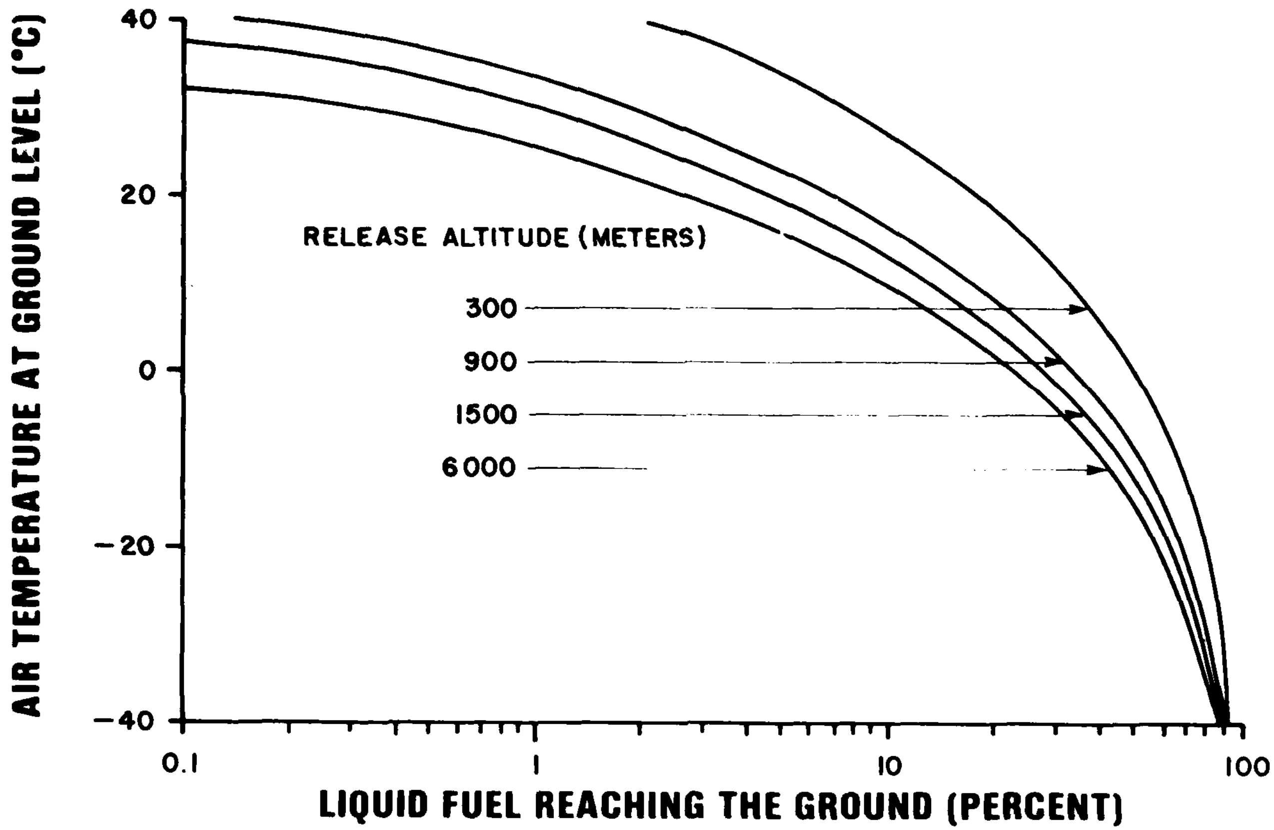

Figure 3b. Effect of Temperature on the Percent of Fuel Reaching the Ground: JP-8/Jet A.

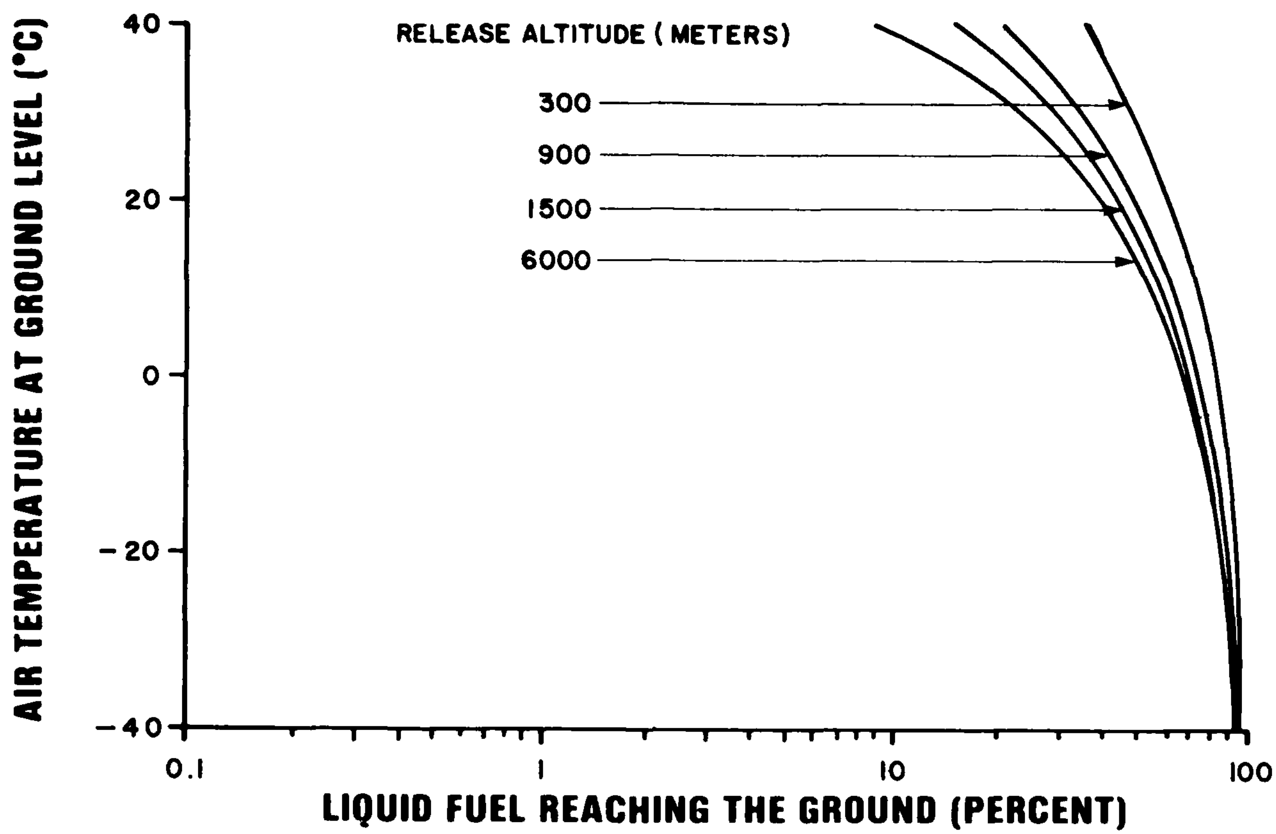

Figure 3c. Effect of Temperature on the Percent of Fuel Reaching the Ground: DF#2.

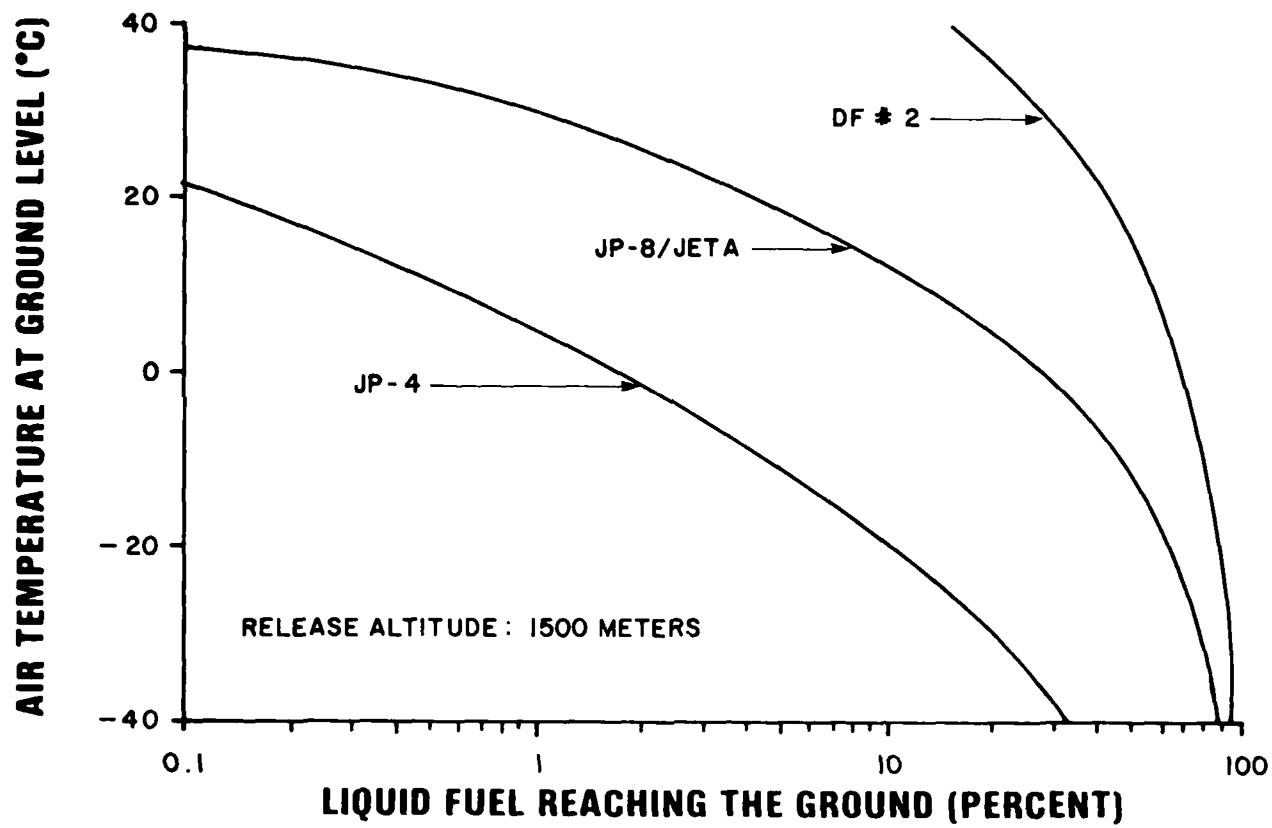

Figure 4. Comparison of Ground Contamination from 1500 Meters for Different Fuels.

Table 2. TIME ELAPSED TILL THE FIRST DROPLETS REACH THE GROUND

a. JP-4

Ground-Level Temperature (°C)	Release Altitude (kilometers)	Time of Fall (minutes)	Average Fall Rate (minutes/kilometer)
-40	6.0	54	9
	3.0	30	10
	1.5	16	11
	0.9	9	10
	0.3	3	10
	Average:		10
-20	6.0	65	11
	3.0	37	12
	1.5	19	13
	0.9	11	12
	0.3	3.5	12
	Average:		12
0	6.0	103	17
	3.0	60	20
	1.5	29	19
	0.9	16	18
	0.3	4.4	15
	Average:		18

Table 2. TIME ELAPSED TILL THE FIRST DROPLETS REACH THE GROUND (CONTINUED)

b. JP-8/Jet A

Ground-Level Temperature (°C)	Release Altitude (kilometers)	Time of Fall (minutes)	Average Fall Rate (minutes/kilometer)
-40	6.0	46	8
	3.0	25	8
	1.5	13	9
	0.9	8	9
	0.3	2.7	9
	Average:		9
-20	6.0	47	8
	3.0	26	9
	1.5	13	9
	0.9	8	9
	0.3	2.7	9
	Average:		9
0	6.0	51	9
	3.0	28	9
	1.5	14	9
	0.9	9	10
	0.3	2.8	9
	Average:		9
20	6.0	67	11
	3.0	38	12
	1.5	19	13
	0.9	10	11
	0.3	3.1	10
	Average:		11
40	6.0	270	[illegible]
	3.0	154	51
	1.5	40	27
	0.9	19	21
	0.3	4.3	14
	Average:		-

Table 2. TIME ELAPSED TILL THE FIRST DROPLETS REACH THE GROUND (CONCLUDED)

c. DF #2

Ground-Level Temperature (°C)	Release Altitude (kilometers)	Time of Fall (minutes)	Average Fall Rate (minutes/kilometer)
-40	6.0	45	8
	3.0	24	8
	1.5	13	9
	0.9	8	9
	0.3	2.6	9
	Average:		9
-20	6.0	46	8
	3.0	25	8
	1.5	13	9
	0.9	8	9
	0.3	2.6	9
	Average:		9
0	6.0	47	8
	3.0	25	8
	1.5	13	9
	0.9	8	9
	0.3	2.7	9
	Average:		9
20	6.0	50	8
	3.0	27	9
	1.5	14	9
	0.9	8	9
	0.3	2.8	9
	Average:		9
40	6.0	56	9
	3.0	31	10
	1.5	15	10
	0.9	9	10
	0.3	2.9	10
	Average:		10

Table 3. RESIDUAL COMPOSITION OF FUEL DROPLETS WHEN THEY REACH THE GROUND

a. Fuel: JP-4
Release Altitude: 1500 Meters
Ground-Level Temperature: -20°C
Liquid Fuel Reaching the Ground: 10.2%

Components	Original Percent of Droplet Mass	Percent Remaining of Component	Percent of Initial Droplet Mass	Percent of Final Droplet Mass
C5* hydrocarbons	3.2	0	-	-
C6 paraffins	7.1	0	-	-
C6 cycloparaffins	2.2	0	-	-
Benzene	0.3	0	-	-
C7 paraffins	8.6	0	-	-
C7 cycloparaffins	7.3	0	-	-
Toluene	0.8	0	-	-
C8 paraffins	9.4	0	-	-
C8 cycloparaffins	7.7	0	-	-
C8 aromatics	1.8	0	-	-
C9 paraffins	8.7	0	-	-
C9 cycloparaffins	4.6	0.3	0.01	0.1
C9 aromatics	2.8	1.6	0.05	0.5
C10 paraffins	7.0	1.0	0.07	0.7
C10 cycloparaffins	3.9	4.2	0.17	1.6
C10 aromatics	2.1	7.4	0.15	1.5
Napthalene	0.3	46.4	0.13	1.3
C11 paraffins	4.7	26.9	1.29	12.6
C11 cycloparaffins	2.7	27.0	0.73	7.1
Dicycloparaffins	4.0	31.0	1.26	12.3
C11 aromatics	1.2	35.4	0.45	4.4
C11 napthalenes	0.3	66.8	0.18	1.7
C12 paraffins	2.8	48.3	1.36	13.3
C12 cycloparaffins	1.3	42.9	0.55	5.4
C12 aromatics	0.6	47.0	0.27	2.6
C12 napthalenes	0.3	78.9	0.21	2.0
C13 paraffins	1.1	63.2	0.71	6.9
C13 cycloparaffins	0.4	55.7	0.24	2.3
C13 aromatics	0.1	61.6	0.07	0.7
C14 hydrocarbons	0.2	73.8	0.15	1.5
C15 hydrocarbons	0.1	81.4	0.08	0.8
Tricycloparaffins	2.2	86.7	1.96	19.1
Residual hydrocarbons	0.2	99.8	0.16	1.6

*That is, components containing 5 carbon atoms

Table 3. RESIDUAL COMPOSITION OF FUEL DROPLETS WHEN THEY REACH THE GROUND (CONTINUED)

b. Fuel: JP-8/Jet A
Release Altitude: 1500 Meters
Ground-Level Temperature: 0°C
Liquid Fuel Reaching the Ground: 28.9%

Components	Original Percent of Droplet Mass	Percent Remaining of Component	Percent of Initial Droplet Mass	Percent of Final Droplet Mass
C8 paraffins	0.3	0	-	-
C8 cycloparaffins	0.2	0	-	-
C8 aromatics	0.1	0	-	-
C9 paraffins	2.1	0	-	-
C9 cycloparaffins	1.5	0	-	-
C9 aromatics	1.1	0	-	-
C10 paraffins	5.0	0	-	-
C10 cycloparaffins	3.5	0.1	0	-
C10 aromatics	2.4	0.2	0	-
C11 paraffins	7.9	5.3	0.42	1.5
C11 cycloparaffins	3.3	5.3	0.17	0.6
Dicycloparaffins	3.4	7.6	0.26	0.9
C11 aromatics	3.8	10.5	0.40	1.4
C12 paraffins	10.0	22.8	2.28	7.9
C12 cycloparaffins	8.7	26.5	2.31	7.9
C12 aromatics	4.9	21.2	1.04	3.6
C13 paraffins	10.8	43.2	4.67	16.1
C13 cycloparaffins	8.4	32.1	2.70	9.3
C13 aromatics	5.3	40.7	2.16	7.5
C14 paraffins	5.5	59.4	3.27	11.3
C14 cycloparaffins	5.1	78.2	3.99	13.8
C14 aromatics	3.2	79.6	2.55	8.8
C15 paraffins	1.3	70.3	0.91	3.1
C15 cycloparaffins	1.1	81.5	0.90	3.1
C15 aromatics	0.7	82.5	0.58	2.0
C16 hydrocarbons	0.2	78.0	0.16	0.6
Residual hydrocarbons	0.2	91.9	0.18	0.6

Table 3. RESIDUAL COMPOSITION OF FUEL DROPLETS WHEN THEY REACH THE GROUND (CONCLUDED)

c. Fuel: DF #2
Release Altitude: 1500 Meters
Ground-Level Temperature: 20°C
Liquid Fuel Reaching the Ground: 46.2%

Components	Original Percent of Droplet Mass	Percent Remaining of Component	Percent of Initial Droplet Mass	Percent of Final Droplet Mass
C10 paraffins	0.8	0	-	-
C10 cycloparaffins	0.6	0	-	-
C10 aromatics	0.4	0	-	-
C11 paraffins	2.0	0	-	-
C11 cycloparaffins	1.8	0	-	-
C11 aromatics	1.0	0	-	-
C12 paraffins	3.4	0.8	0.03	0.1
C12 cycloparaffins	2.9	1.3	0.04	0.1
C12 aromatics	1.6	0.6	0.01	0
C13 paraffins	5.8	8.1	0.47	1.0
C13 cycloparaffins	4.6	2.7	0.12	0.3
C13 aromatics	2.9	6.4	0.19	0.4
C14 paraffins	8.0	25.5	2.04	4.4
C14 cycloparaffins	7.4	60.9	4.51	9.8
C14 aromatics	4.7	64.1	3.01	6.5
C15 paraffins	6.8	44.6	3.03	6.5
C15 cycloparaffins	5.9	68.6	4.05	8.8
C15 aromatics	3.6	71.3	2.57	5.6
C16 paraffins	5.3	60.6	3.21	6.9
C16 cycloparaffins	4.6	65.8	3.03	6.5
C16 aromatics	2.8	80.0	2.24	4.8
C17 paraffins	5.1	71.7	3.66	7.9
C17 cycloparaffins	4.3	74.8	3.22	7.0
C17 aromatics	2.5	72.1	1.80	3.9
C18 paraffins	4.0	73.5	2.94	6.4
C18 cycloparaffins	3.4	82.7	2.81	6.1
C18 aromatics	2.1	83.4	1.75	3.8
C19 paraffins	0.7	82.1	0.52	1.1
C19 cycloparaffins	0.6	85.9	0.58	1.3
C19 aromatics	0.4	89.5	0.36	0.8

SECTION V
CONCLUSIONS

The results presented in the previous section indicate that fuel composition, in so far as it determines the fuel's volatility and boiling range, has a significant effect on the extent of ground contamination by fuel jettisoned from aircraft. For JP-4, which is a highly volatile naptha fraction, no appreciable ground contamination is likely to occur except for jettisoning very close to the ground or at extremely low ambient temperatures. This is in contrast with JP-8 and Jet A, which are much less volatile kerosene fractions; they can be expected to reach the ground in considerable quantities unless the ambient temperature is quite warm and the release altitude is well above the ground. In the extreme case of jettisoning DF #2, a large fraction of the fuel would reach the ground under any circumstances. The different predictions for the three fuels are summarized in Figure 5.

A previous study of the enviornmental impact of fuel jettisoning (Reference 1) considered only JP-4 fuel, and concluded that the effect of the evaporated fuel vapors in the atmosphere is negligible. The only concern for detriment of the environment stemmed from the possibility of liquid fuel contaminating ground or water resources. In the case of JP-4, this was not a likely event. However, for jettisoning of JP-8 or Jet A, the likelihood of significant quantities of liquid fuel reaching the ground is much higher. Figure 5 shows that when the temperature at the ground is below freezing (0°C), more than 20 percent of jettisoned JP-8 or Jet A will reach the ground before evaporating, regardless of the jettisoning altitude. Even for temperatures above 20°C (70°F), several percent of the jettisoned fuel will reach the ground in liquid droplets. Although the effects of the evaporated JP-8 or Jet A vapors can be neglected, the possibility of surface contamination cannot.

Air Force aircraft in NATO and commercial aircraft in the US jettison JP-8 and Jet A regularly. The Air Force jettisoning occurs primarily over the North Sea, but much of it is directly over England (Reference 1). Responsible personnel in this area should be made aware of the increased potential for ground contamination as a result of the conversion from JP-4 to JP-8. The locations and circumstances of commercial fuel jettisioning have never been surveyed, despite the recommendation of the General Accounting Office (Reference 7). Because of the higher likelihood of ground contamination following jettisoning of these fuels, the choice of jettisoning locations becomes more critical than with JP-4.

Air Force command directives specify that, when circumstances permit, fuel jettisoning should be carried out over unpopulated areas and more than 1500 meters (5000 feet) above the ground (Reference 1). As can be seen in Figure 2, jettisoning above 1500

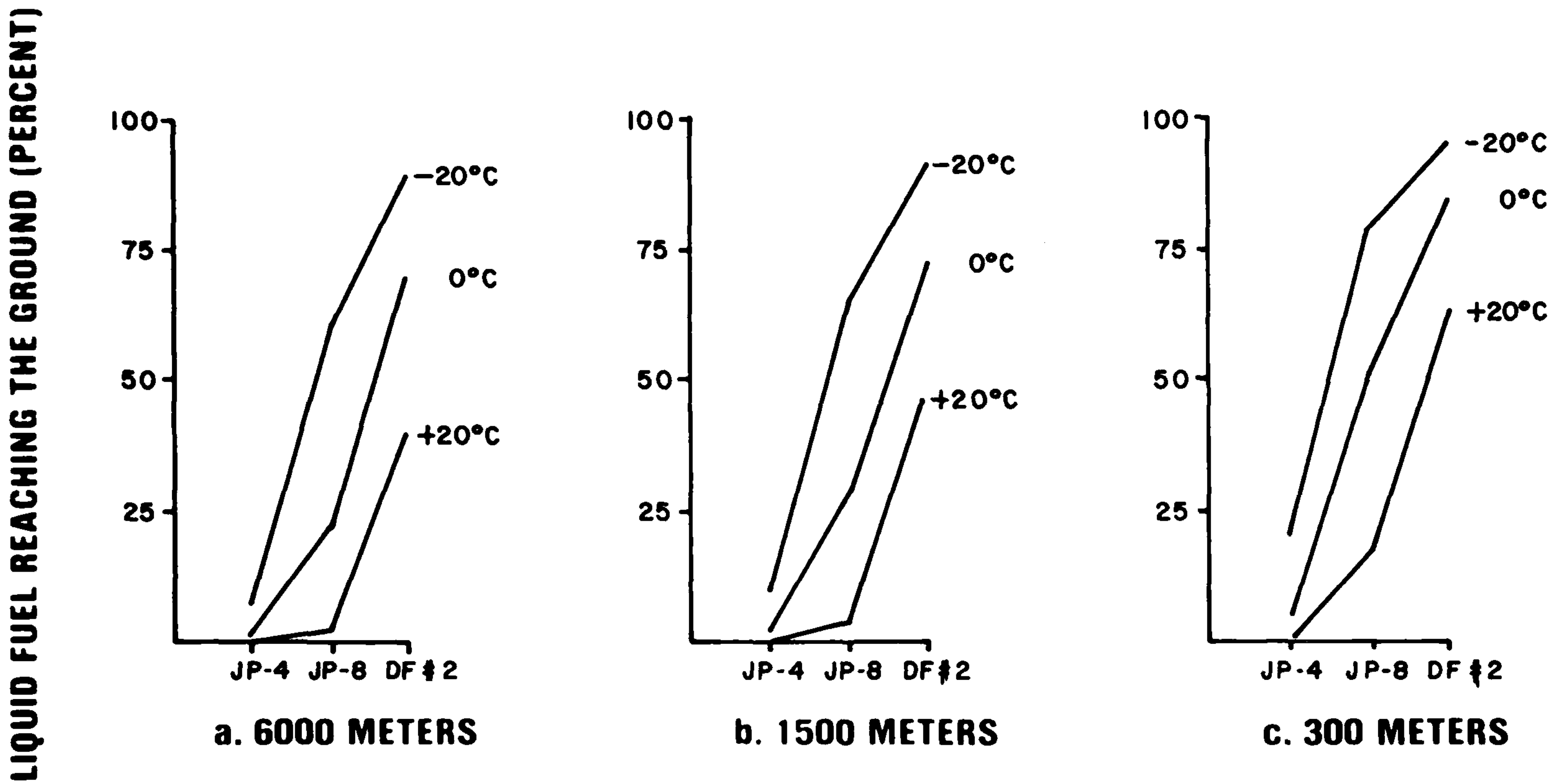

Figure 5. Effect of Fuel Composition on the Percent of Fuel Reaching the Ground.

meters is preferred to allow sufficient time for the fuel to evaporate as much as possible. For the larger fuel dumps performed by tanker and bomber aircraft, release altitudes above 6000 meters (20,000 feet) are specified. While increasing the release altitude from 1500 to 6000 meters does not significantly decrease the fraction of fuel reaching the ground, it does allow considerably more time for atmospheric processes to disperse the fuel. The FAA guidelines for jettisoning by commerical aircraft suggest only a 600-meter (2000-foot) minimum altitude (Reference 7). However, following Air Force guidance of 1500 meters (6000 meters for large aircraft such as the Boeing 747) would help to minimize any detriment to the environment from the jettisoning of Jet A by commercial aircraft.

Due to uncertainty concerning the eventual properties and specifications of future fuels, it is not possible to predict the precise effect of future conversion to broadened-specification fuels on the environmental consequences of fuel jettisoning. However, it is clear from Figure 5 that, as the boiling range of future fuels increases from that of JP-4 or JP-8 toward that of DF #2, the potential for ground contamination by jettisoned fuel will increase dramatically. Since fuel jettisoning appears to be an unavoidable concomitant of aircraft operations, it is important to recognize the need for increased awareness of the potential for environmental harm from fuel jettisoning as new fuel specifications are set.

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